Appendix A. Quality Assurance

A major pre-requisite for establishing quality control standards for wind measurements is a strong quality assurance program. Remember the mantra that good QC requires good QA, and good QA requires good scientists, engineers, and technicians.

A good QA effort continually seeks to ensure that end data products are of high value and strives to prove they are free of error. Operators should seek out partnering opportunities to inter-compare systems by co-location of differing sensors, thereby demonstrating high quality by both to the extent that there is agreement and providing a robust measure of observation accuracy by the level of disagreement. Operators should also, if possible, retain an alternate sensor or technology from a second vendor for similar in-house checks.

The lists in the following sections suggest ways to ensure QA by using specific procedures and techniques. Operators should also follow instructions provided by the sensor manufacturer.

A.1 Sensor Calibration Considerations

Observations must be traceable to one or more accepted standards through a calibration performed by the manufacturer and/or the operator. If the calibration is conducted by the manufacturer, the operator must also conduct some form of an acceptable calibration check.

NIST provides a wealth of information on standards and calibrations for many variables, including wind observations (http://www.nist.gov/calibrations/upload/sp250_79-2.pdf). Virtually all manufacturers provide calibrations traceable to NIST standards as part of their standard product services.

An often overlooked calibration or calibration check can be performed by choosing a consensus standard. For example, deriving the same answer (within acceptable levels of data precision or data uncertainty) from four different sensors of four different vendors, preferably utilizing several different technologies, constitutes an acceptable check. Because of the trend towards corporate conglomeration, those wishing to employ a consensus standard should ensure that the different vendors are truly independent.

A.2 Sensor Comparison

An effective QA effort continually strives to ensure that end data products are of high value and to prove they are free of error. Operators should seek out partnering opportunities to inter-compare systems by co-locating differing sensors. Agreement of multiple systems would provide a robust observation, while disagreement may offer a measure of data uncertainty. If possible, operators should retain an alternate sensor or technology from a second vendor for similar in-house checks. For resource-constrained operators, however, it may not be possible to spend the time and funds needed to procure and maintain two systems. For those who do so and get two different results, the use of alternate sensors or technologies provide several important messages: a) a measure of corporate capabilities; b) a reason to investigate, understand the different results, and take corrective action; and c) increased understanding that when variables are measured with different technologies, different answers can be correct, and they must be understood in order to properly report results. For those who succeed, the additional sensors provide a highly robust demonstration of capability. Such efforts form the basis of a strong QA/QC effort. Further, it provides the operator with an expanded supply source, permitting less reliance upon a single vendor and providing competition that is often required by procurement offices. Although not real time, an alternative approach to monitoring stability of a sensor is comparison with remotely sensed data from satellite or radar (ideally two additional sources of observations so it is clear which instrument is drifting).

A.3 Common QA Considerations

In addition to the more generic QA processes listed below, these critical QA considerations specific to wind observations were highlighted by the manual committee and others who reviewed the manual:

- Carefully address the initial sensor alignment, correcting for magnetic deviation and variation as appropriate, and provide this information in the metadata. For vessel-mounted anemometers, do the same for the vessel heading.
- Fully describe the signal processing used to compute the observations in the metadata – sampling frequency, averaging period, outlier removal, etc.
- Fully document the anemometer height relative to a valid, useful, standard datum such as NAVD88. Provide photographs of the surrounding vicinity. If the observations are site-specific and not representative of the greater area (for example, a ferry dock with a nearby terminal building), note that in the metadata.

The following lists suggest ways to ensure QA by using specific procedures and techniques:

- Perform pre-deployment calibrations on every sensor.
- Perform post-deployment calibrations on every sensor, plus in-situ comparison before recovery.
- Perform periodic calibration of ready-to-use spares.
- Monitor with redundant sensors whenever possible.
- Record all actions related to sensors – calibration, cleaning, deployment, etc.
- Monitor battery voltage and watch for unexpected fluctuations.

When evaluating which instrument to use, consider these factors:

- Selection of a reliable and supportive manufacturer and appropriate model
- Operating range (i.e., instrument operation can be limited by temperature or sensor span)
- Resolution/precision required
- Sampling frequency – how fast sensor can take measurements
- Reporting frequency – how often the sensor reports the data
- Response time of the sensor – sensor lag – time response
- Power check – master clock, battery, etc. – variability in these among sensors
- Standardize sensor clock to a reference such as Global Positioning System or GPS timing
- Capability to reveal a problem with data

When evaluating which specifications must be met:

- State the expected accuracy.
- Ensure sensor calibration stability.
- Determine how the sensor compares to the design specifications.
- Determine if the sensor meets those specifications.
- Include photos showing surrounding area to identify any nearby obstructions
- Determine whether result is good enough (fit for purpose: data are adequate for nominal use as preliminary data).

General comments regarding QA procedures:

- A diagram (http://www.ldeo.columbia.edu/~dale/dataflow/), contributed by Dale Chayes (LDEO) provides a visual representation of proper QA procedures.
- Require serial numbers and model ID from the supplier.
- Do not make the checklist so detailed that it will not be used.
- Do not assume the calibration is perfect (could be a calibration problem rather than a sensor problem).
- Keep good records of all related sensor calibrations and checks (e.g., temperature).
- Use NIST-traceable instrumentation when conducting calibrations or calibration checks.
- A sensor that maintains an internal file of past calibration constants is very useful since it can be downloaded instead of transcribed manually introducing human error.

The calibration constants or deviations from a standard should be plotted over time to determine if the sensor has a drift in one direction or another. A sudden change can indicate a problem with the sensor or the last calibration.

A.4 QA Levels for Best Practices

A wide variety of techniques are used by operators to assure that sensors are properly calibrated and operating within specifications. While all operators must conduct some form of validation, there is no need to force operators to adhere to one single method. A balance exists between available resources, level of proficiency of the operator, and target data reproducibility requirements. The various techniques span a range of validation levels and form a natural hierarchy that can be used to establish levels of certification for operators (table A-1). The lists in the following sections suggest ways to ensure QA by using specific procedures and techniques.

Table A-1. Best practices indicator for QA

QA Best Practices Indicator	Description
Good Process	Sensors are swapped and/or serviced at sufficient regular intervals. Sensors are pre- and post-deployment calibration checked.
Better Process	Good process, plus an overlapping operational period during sensor swap-out to demonstrate continuity of observations.
Best Process	Better process, and follow a well-documented protocol or alternative sensors to validate in-situ deployments. Or, the better process employing manufacturer conducted pre- and post-calibrations.

A.5 Additional Sources of QA Information

Wind sensor operators also have access to other sources of QA practices and information about a variety of instruments. For example, the Alliance for Coastal Technologies (ACT) serves as an unbiased, third party test bed for evaluating sensors and platforms for use in coastal and ocean environments. ACT conducts instrument performance demonstrations and verifications so that effective existing technologies can be recognized and promising new technologies can become available to support coastal science, resource management, and ocean observing systems (ACT 2012). The NOAA Ocean Systems Test and Evaluation Program (OSTEP) also conducts independent tests and evaluations on emerging technology as well as new sensor models. Both ACT and OSTEP publish findings that can provide information about QA, calibration, and other aspects of sensor functionality. The following list provides links to additional resources on QA practices.

- Manufacturer specifications and supporting Web pages/documents
- QARTOD –http://www.ioos.noaa.gov/qartod/
- ACT - http://www.act-us.info/
- CO-OPS - http://tidesandcurrents.noaa.gov/pub.html under the heading Manuals and Standards
- NDBC http://www.ndbc.noaa.gov/

The following samples provide hints for development of deployment checklists taken from QARTOD IV:

Pre-deployment QA Checklist

- ❒ Read the manual.
- ❒ Establish, use, and submit (with a reference and version #) a documented sensor preparation procedure (protocol). Maintain the sensor according to the manufacturer's procedures.
- ❒ Calibrate sensor against an accepted standard and document (with a reference and version #).
- ❒ Compare the sensor with an identical, calibrated sensor measuring the same thing in the same area (in a calibration lab).
- ❒ View calibration specifications with a critical eye (don't presume the calibration is infallible). Execute detailed review of calibrated data.
- ❒ Check the sensor history for past calibrations, including a plot over time of deviations from the standard for <u>each</u> (this will help identify trends such a progressively poorer performance). Control chart calibrations.
- ❒ Check the sensor history for past repairs, maintenance, and calibration.
- ❒ Consider storing and shipping information before deploying.
    - Heat, cold, vibration, etc.
- ❒ Provide detailed documentation.
- ❒ Record operator/user experiences with this sensor after reading the manual.
- ❒ Search the literature for information on your particular sensor(s) to see what experiences other researchers may have had with the sensor(s).
- ❒ Establish and use a formal pre-deployment checklist.
- ❒ Ensure that technicians are well-trained. Use a tracking system for training to identify those technicians who are highly trained and then pair them with inexperienced technicians. Have a data quality review chain.

Deployment Checklist

- ❒ Verify sensor serial numbers.
- ❒ Deploy and co-locate multiple sensors (attention to interference if too close).
- ❒ Perform visual inspection; take photos if possible (verify position of sensors, connectors, and cable problems).
- ❒ Verify instrument function at deployment site prior to site departure.
- ❒ Monitor sensors for issues (freezing, corrosion).
- ❒ Automate processing so you can monitor the initial deployment and confirm the sensor is working while still on-site.
- ❒ Specify date/time for all recorded events. Use GMT or UTC.
- ❒ Check software to ensure that the sensor configuration and calibration coefficients are correct. Also check sampling rates and other timed events, like time averaging.
- ❒ Visually inspect data stream to ensure reasonable values.
- ❒ Note weather conditions and members of field crew.
- ❒ Record and routinely verify metadata (e.g., sensor position and orientation). This information is vital to the value of data for many applications. For example, wind speed measurements are very dependent on measurement height relative to the surface. If this height is not known, the value of the data is greatly diminished.

Post-deployment Checklist

- ❐ Take pictures of recovered sensor (as is) for metadata.
- ❐ Check to make sure all clocks agree or, if they do not agree, record all times and compare with NIST.
- ❐ Post-calibrate sensor and document readings.
- ❐ Perform in-situ side by side check using another sensor.
- ❐ Provide a mechanism for feedback on possible data problems and/or sensor diagnostics.
- ❐ Clean and store the sensor properly or redeploy.
- ❐ Visually inspect physical state of instrument.
- ❐ Verify sensor performance by:
    - Checking nearby stations;
    - Making historical data comparisons (e.g., long-term time-series plots, which are particularly useful for identifying long-term calibration drift).